



## NASA SBIR 2022 Phase I Solicitation

### 27.04 Landing Systems Technologies

Lead Center: MSFC

Participating Center(s): GRC, LaRC

#### Scope Title

Plume-Surface Interaction (PSI) Instrumentation, Ground Testing, and Analysis

#### Scope Description

As NASA and commercial entities prepare to land robotic and crewed vehicles on the Moon, and eventually Mars, characterization of landing environments is critical to identifying requirements for landing systems and engine configurations, instrument placement and protection, and landing stability. The ability to predict the extent to which regolith is liberated and transported in the vicinity of the lander is also critical to understanding the effects on precision landing sensor requirements and landed assets located in proximity. Knowledge of the characteristics, behavior, and trajectories of ejected particles and surface erosion during the landing phase is important for designing effective sensor systems and PSI risk mitigation approaches. Mission needs to consider include landers with single and multiple engines, both pulsed and throttled systems, landed mass from 400 to 40,000 kg, and both lunar and Mars destinations.

NASA is seeking support in the following areas:

1. Ground test data, test techniques, and diagnostics across physical scales and environments, with particular emphasis on nonintrusive approaches and methodologies.
2. PSI-specific flight instrumentation, with particular emphasis on in situ measurements of particle size and particle velocity during the landing phase.
3. Solutions to alleviate or mitigate the PSI environments experienced by propulsive landers&#128;&#148;not vehicle-specific solutions.
4. Validated, robust, and massively parallel computational fluid dynamics (CFD) models and tools for predicting PSI physics for plumes in low-pressure and rarefied environments, time-evolving cratering and surface erosion, and near-field and far-field ejecta transport.

NASA has plans to purchase services for payload delivery to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant PSI technologies in the lunar environment. The CLPS payload accommodations will vary depending on the service provider and mission characteristics, but the data to be obtained or mitigations to be demonstrated should be broadly applicable to other future landing systems. Additional information on the CLPS program and providers can be found at this link: <https://www.nasa.gov/content/commercial-lunar-payload-services>. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-

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sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services are currently under contract, and flight opportunities are expected to continue well into the future. In future years, it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.

### **Expected TRL or TRL Range at completion of the Project**

3 to 6

### **Primary Technology Taxonomy**

#### **Level 1**

TX 09 Entry, Descent, and Landing

#### **Level 2**

TX 09.3 Landing

### **Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Hardware
- Software

### **Desired Deliverables Description**

Deliverables of all types can be infused into the prospect missions due to early design maturity.

For PSI ground test data, flight instrumentation, diagnostics, and mitigation approaches, Phase I deliverables should include detailed test plans, with prototype and/or component demonstrations as appropriate. Phase II deliverables should include complete data products, fully functional hardware, and validated performance in relevant environments.

For PSI modeling and simulation, Phase I deliverables should demonstrate proof of concept and a minimum of component-level verification, with detailed documentation on future data needs to complete validation of the integrated model and uncertainty quantification methodology. Phase II deliverables must demonstrate verification and validation beyond the component level, with validation demonstrated through comparisons with relevant data and documented uncertainty quantification. Significant attention should be applied to create highly robust and extremely high-performance computational simulation tool deliverables, exploiting leading-edge computational architectures to achieve this performance.

### **State of the Art and Critical Gaps**

The characteristics and behavior of airborne particles during descent is important for designing descent sensor systems that will be effective. Furthermore, although the physics of the atmosphere and the characteristics of the regolith are different for the Moon, the capability to model PSIs on the Moon will feed forward to Mars, where it is critical for human exploration.

Currently, flight data are collected from early planetary landing, and those data are fed into developmental tools for validation purposes. The validation data set, as well as the expertise, grows as a result of each mission and is shared across and applied to all other missions. We gain an understanding of how various parameters, including different types of surfaces, lead to different cratering effects and plume behaviors. The information helps NASA and industry make lander design and operations decisions. Ground testing (‘unit tests’) is used early in the development of the capability in order to provide data for tool validation.

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The current postlanding analysis of planetary landers (on Mars) is performed in a cursory manner with only partially empirically validated tools because there has been no dedicated fundamental research investment in this area. Flight test data does not exist in the environments of interest.

### **Relevance / Science Traceability**

Current and future lander architectures will depend on knowledge of PSI, such as:

- Artemis human landing system (HLS).
- Commercial robotic lunar landers (CLPS or other).
- Planetary mission landers (Mars Sample Retrieval Lander and others).
- Human Mars landers.

### **References**

- Lander Technologies: <https://www.nasa.gov/content/lander-technologies>
- Metzger, Philip, et al. (2009). ISRU implications for lunar and martian plume effects. 47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition.
- Plemmons, D. H., et al. (2008). Effects of the Phoenix Lander descent thruster plume on the Martian surface. *Journal of Geophysical Research: Planets*, 113(E3).
- Mehta, M., et al. (2013). Thruster plume surface interactions: Applications for spacecraft landings on planetary bodies. *AIAA Journal*, 51(12), 2800-2818.
- Vangen, Scott, et al. (2016). International Space Exploration Coordination Group Assessment of Technology Gaps for Dust Mitigation for the Global Exploration Roadmap. AIAA SPACE 2016. 5423.

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### **Scope Title**

Landing Shock Attenuation, Reusability, and In Situ Landing Sensors

### **Scope Description**

Novel and creative solutions will be required to attenuate the structural loads induced by the landing of crewed spacecraft, commercial cargo payloads, scientific payloads, critical surface assets, and surface habitats on the Moon and Mars. In principle, the mass and scale of these spacecraft, payloads, and assets could range from something akin to a small-satellite class, roughly 10 to 500 kg, to masses on the order of thousands of kg. This capability is critical for landing larger spacecraft near assets already in place.

Current landing system solutions include legs, shock absorbers, inflatables, crushables, sky cranes, pallets, etc., but new technologies, novel combinations of existing technologies, and/or the repurposing of current Earth-based technologies could enable new mission design and feasibility.

Mission concepts requiring the sustainability and reusability of assets and payloads on the surfaces of celestial bodies (including the Moon, Mars, moons of Mars, comets, and/or asteroids) will benefit from the development of reusable landing systems, including consideration of launch plumes for ascent vehicles. Reusability can also be interpreted to include the postlanding adaptation of landing systems to enable mobility or augmented capabilities (e.g., "touch-and-go" mobility, grappling, maneuverability, etc.).

In situ landing sensors that measure the induced loads and shocks experienced within these challenging environments will provide engineers and researchers with valuable in situ data, which will enable improved environmental modeling, landing structure design, and sensor design. Possible applications include advanced touchdown sensors, measurement of payload orientation, stability, and/or landing loads.

Also, of interest are approaches for achieving multifunctional components, repurposing landing structures for postflight mission needs such as payload placement or mobility, and incorporating design features that reduce operating complexity.

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Under this subtopic, proposals may include efforts to develop prototypes for flight demonstration of relevant technologies in the lunar environment or in terrestrial testbeds. The Commercial Lunar Payload Services (CLPS) accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: <https://www.nasa.gov/content/commercial-lunar-payload-services>. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin as early as 2022, and flight opportunities are expected to continue well into the future. In future years, it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.

### **Expected TRL or TRL Range at completion of the Project**

3 to 6

### **Primary Technology Taxonomy**

#### **Level 1**

TX 09 Entry, Descent, and Landing

#### **Level 2**

TX 09.3 Landing

### **Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Hardware
- Software

### **Desired Deliverables Description**

Deliverables and/or prototypes of all types can be infused into the prospective missions due to early design maturity.

Phase I deliverables should include preliminary designs, end-product test plans, and component-level testing and/or demonstrations as appropriate, and Phase II should include a working prototype demonstration in a relevant environment.

### **State of the Art and Critical Gaps**

Robust landing structures can enable lunar and Mars global access with 20-ton payloads to support human missions.

Mission risks related to hazard avoidance may be partially mitigated by robust landing system accommodation of landing hazards.

Development of exploration technologies to enable a vibrant space economy can be partially addressed with respect to landing technologies related to landing pads and protective and robust landing structures.

Construction and outfitting of assets on the Moon and Mars could be addressed by technologies related to multifunctional and adaptive landing structures for use after landing.

### **Relevance / Science Traceability**

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Current and future lander architectures will depend on landing shock attenuation, reusability, and intelligent landing sensors, such as:

- Artemis human landing system (HLS).
- Commercial robotic lunar landers (CLPS or other).
- Planetary mission landers (Mars Sample Retrieval Lander and others).
- Human Mars landers.
- Scientific investigations of comets and asteroids.

## References

- Lander Technologies: <https://www.nasa.gov/content/lander-technologies>
- Commercial Lunar Payload Services: <https://www.nasa.gov/content/commercial-lunar-payload-services>
- Lunar Exploration and Transportation Services: <https://www.nasa.gov/nextstep/humanlander3>
- JAXA Hayabusa2: <https://www.hayabusa2.jaxa.jp/en/>
- JPL ATHLETE Rover: <https://www-robotics.jpl.nasa.gov/systems/system.cfm?System=11>
- SLS-SPEC-159 Cross-Program Design Specification for Natural Environments (DSNE)